Center Independent Research & Development: JPL IRAD

Multiwavelength Digital Holography for Spectral Discrimination of Bacteria and Minerals

Completed Technology Project (2016 - 2019)

Project Introduction

We have previously developed a digital holographic microscope with submicrometer resolution, a cubic mm scale sample volume, and video frame rates to search for microbial life in liquid environments. In this task we will add multi-wavelength capability to this design to enable spectral imaging. This additional capability will allow for better discrimination between abiotic and potentially biotic objects in the sample. The interferometric nature of the instrument and our ability to separate the wavelengths by fringe angle makes it possible to do this without increasing the data volume, providing a naturally compressed data stream.

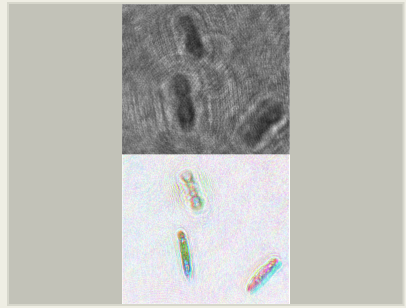
In the current single-wavelength implementation, the holographic information is encoded with fringes in a single, unique orientation of the detector plane. However, if for each new wavelength we add, we encode the new fringe in a unique geometry – then we have increased the capability without increasing complexity. The figure in the appendix illustrates the beam pattern for the following example: 405 nm generating fringes at 45 degrees, 488 nm generating fringes at -45 degrees, and 532 nm at 0 degrees). There is no change to the detector, or the image recording process; the only changes are to the 1) source optics and 2) sample chamber, and the 3) reconstruction process. The object beam for each wavelength goes through the central sample volume, while the reference beams are kept apart.

The goal of this work is to increase by almost an order of magnitude our knowledge of the spectral behavior our our samples – in both amplitude and phase. We note that within JPL as well as in the astrobiology instrument community, we are the only team working on digital holographic microscopy, and currently the only capability we have is monochromatic.

Once we have done the engineering design, implementation and lab testing in years one and two, we plan to carry out our field tests in year three. Specifically, we would like to continue testing our instrument in extreme environments here on Earth. This is less well defined at the moment, but our designs are currently compatible with extreme thermal and pressure environments. We plan to start in nearby locations with extreme environments (e.g., Mono Lake, Salton sea), and are also considering sub-glacial lakes, archaic glacial fields, and deep oceanic vents as prime examples where this new capability can be demonstrated.

Anticipated Benefits

Astrobiology has until very recently been focused on biomarkers that indicate habitability and/or possible detection of long extinct life. **With the creation of the Ocean Worlds program, NASA now has direction to search for extant life elsewhere in the solar system. The Europa Lander Science Definition Team report specifically identifies high resolution, high sensitivity microscopes as a need area.** Chemical biomarkers are



False-color Image of three Euglena (bottom) reconstructed from a three-wavelength hologram (top). The holographic recording enables simultaneous capture of the moving Euglena. The image shows reconstruction in a single focal plane.

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insufficient to unambiguously distinguish extant from extinct life and habitability. Indeed, most complex chemical indicators for life (or proto-life) are very Earth-life-centric (e.g, DNA, RNA) and not universally detectable by chemical means. There is ocean life on earth that can't be detected using known polymerase chain reaction chemistry. On Earth, microscopy is the primary method for initial detection and characterization of new microscopic life forms; we know of no life forms on earth that were not initially detected by visual observation. Even when subsequent colony analysis can be done through mass collection and processing, microscopy is essential. Moreover, the method of Digital Holographic Microscopy (DHM) – a compact instrument with no moving parts yet high imaging volume - is ideally suited to planetary exploration, offering much higher throughput at high resolutions and able to effectively observe translucent objects with or without dyes. Indeed, our current single-wavelength DHM instrument [1] has directly detected bacteria in extreme environments: 1) the sea ice of Greenland – in situ [2], and 2) Mono Lake [pH 10] and the Salton Sea [pH 8.5]. Extending our DHM instrument with multi-wavelength capability enables identification of spectral features intrinsic to detected objects. This helps characterize potential life and identify mineral grains in the absence of life. We know of no other microscopes in development for planetary missions that have sufficient resolution to detect bacterial and archaeal life, whether on Earth or elsewhere. The proposed effort will help maintain and extend the lead that JPL and Caltech currently have in this critical part of the newly developed Ocean Worlds program.

In addition to the Europa Lander concept, this technology will also provide benefits to other potential life detection missions to Enceladus, Mars, Venus, as well as the other icy moons of the outer planets.

Organizational Responsibility

Responsible Mission Directorate:

Mission Support Directorate (MSD)

Lead Center / Facility:

Jet Propulsion Laboratory (JPL)

Responsible Program:

Center Independent Research & Development: JPL IRAD

Project Management

Program Manager:

Fred Y Hadaegh

Project Manager:

Fred Y Hadaegh

Principal Investigator:

Christian A Lindensmith

Co-Investigators:

Jay Nadeau
Eugene Serabyn
Kent T Wallace

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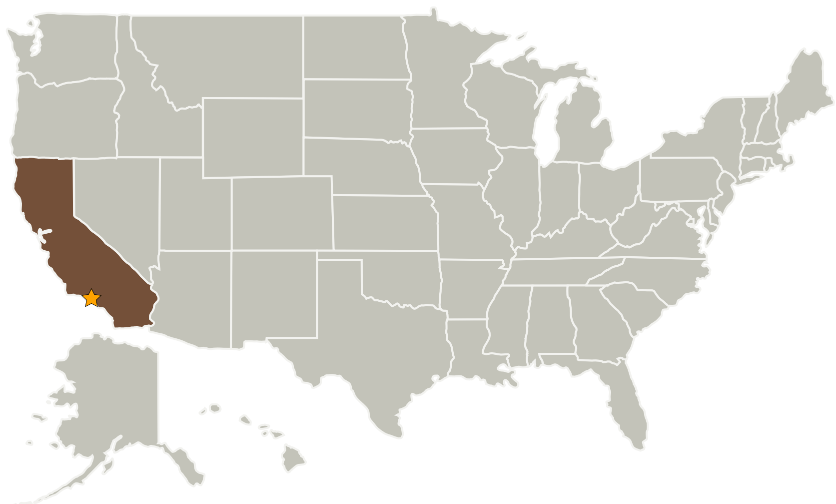
Primary U.S. Work Locations and Key Partners

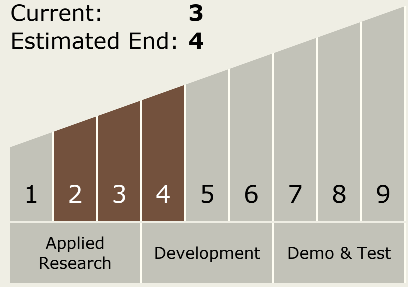


Organizations Performing Work	Role	Type	Location
Jet Propulsion Laboratory(JPL)	Lead Organization	NASA Center	Pasadena, California

Primary U.S. Work Locations
California

Technology Maturity (TRL)

Start: **2**
Current: **3**
Estimated End: **4**



Technology Areas

Primary:

- TX04 Robotic Systems
  - └ TX04.3 Manipulation
    - └ TX04.3.4 Sample Acquisition and Handling

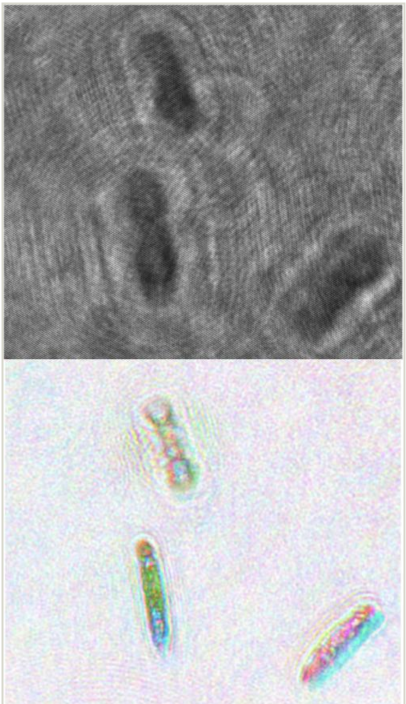
Target Destinations

Others Inside the Solar System, Foundational Knowledge

Supported Mission Type

Push

Images



JPL_IRAD_Activities Project Image
False-color Image of three Euglena (bottom) reconstructed from a three-wavelength hologram (top). The holographic recording enables simultaneous capture of the moving Euglena. The image shows reconstruction in a single focal plane.
(https://techport.nasa.gov/image/27906)

Project Website:

http://motility.caltech.edu